HYDROLOGY AND WATER RESOURCES OF THE LAKE TAHOE REGION

A Guide for Planning

Prepared for
Tahoe Regional Planning Agency
and
Forest Service, U. S. Department of Agriculture

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Establishment of the Tahoe Regional Planning Agency was consented to by the Congress through enactment of Public Law 91-148. On March 19, 1970, the governors of Nevada and California signed the proclamation that proclaimed creation of the Tahoe Regional Planning Agency. Since the authorized staff of the Agency was small, it enlisted help from several committees composed of technical specialists and other citizens concerned with resource conservation and orderly development of the Tahoe environmental resources.

The planning effort has been aided greatly by generous cooperation from numerous federal, state, county, and municipal agencies and from several colleges and interested private individuals. Cooperating agencies included:

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Department of Agriculture: Forest Service; Soil Conservation Service

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Department of Transportation: Coast Guard; Federal Highway Administration; Federal Aviation Administration

State:

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Nevada: The Nevada Department of Conservation and Natural Resources

County and Municipal:

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Any publication that compiles and presents information from so large and disparate a group of contributors as this one does is susceptible to error, inconsistency, and omission. Sustained effort has been made to avoid these flaws; but if it has failed occasionally, the reader's forbearance is humbly solicited.

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This report on the hydrology of the Lake Tahoe Region was prepared by a technical committee sponsored jointly by the Tahoe Regional Planning Agency and the U. S. Forest Service. This committee acknowledges generous cooperation and aid from many of the agencies listed on p. ii. Members of the committee on Hydrology are:

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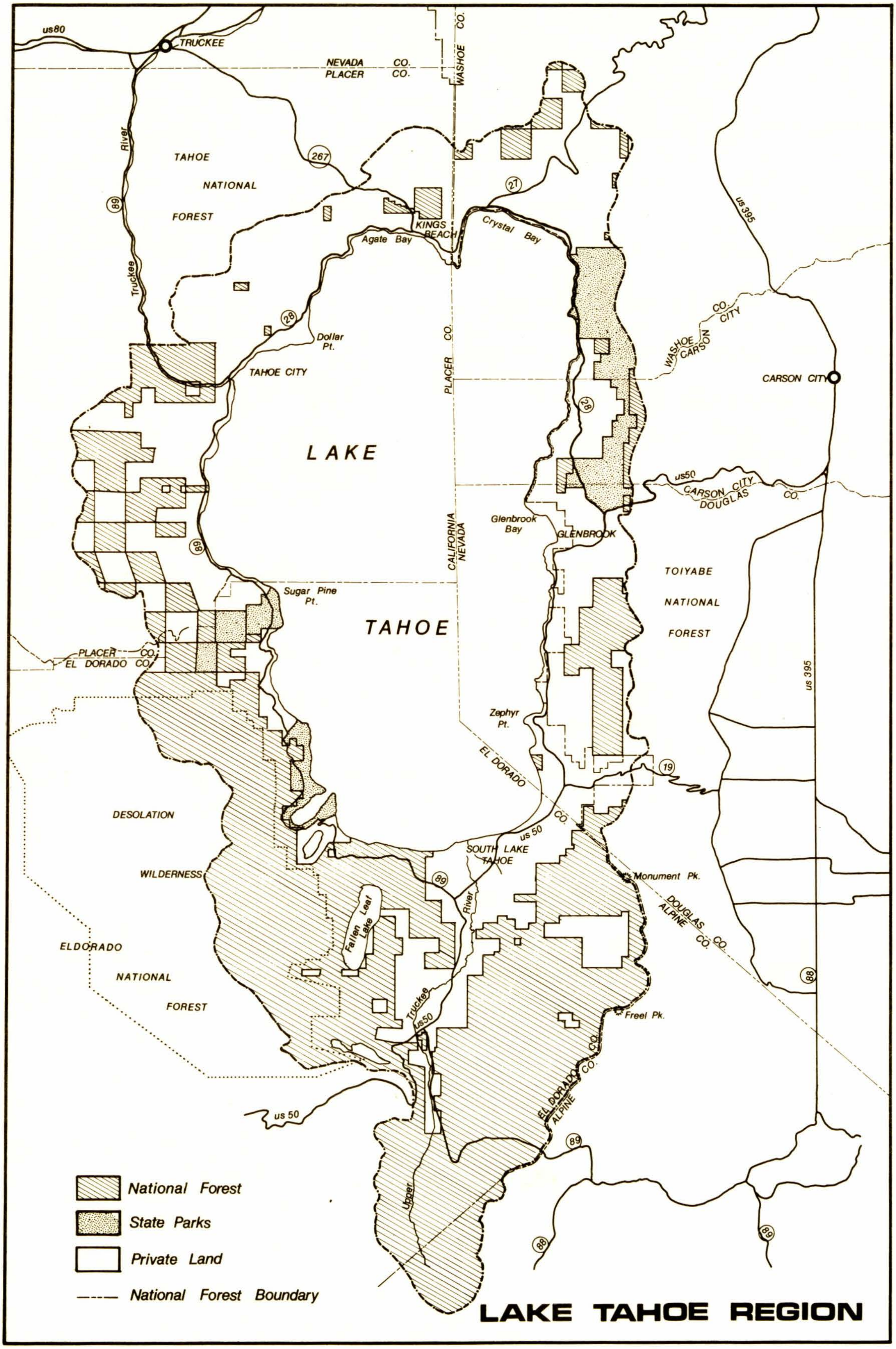

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LAKE TAHOE REGION

INTRODUCTION

General Features of the Lake Tahoe Planning Area

Lake Tahoe and the mountainous timber-covered basin immediately surrounding it provide one of the most beautiful environments in the Sierra Nevada and in the nation. The Lake itself, an irregular oval about 22 miles long by 12 miles wide, covers 191 square miles; it occupies a deep depression between crests of the Sierra Nevada and Carson ranges. Since its surface is 6,225 feet above mean sea level, Lake Tahoe is one of the largest high-altitude lakes in the world. The clarity and purity of its water are outstanding. In fact, protection of quality of the water in Lake Tahoe is a primary objective for effective control of the region's environment.

The spectacular scenery of the Lake Tahoe Region results from unique geological conditions that prevailed when the lake was formed. The basement rock is predominantly granite related to the rocks found throughout the Sierra Nevada. On the other hand, the geologic structure – the faulting that produced the lake basin itself – is related to the Basin Ranges that extend eastward from the Sierra to the Wasatch Range in Utah. The lake was formed by a natural dam – a great pile of andesitic flows – across the north outlet.

Lake Tahoe is on the eastern boundary of that part of the Sierra Nevada that was extensively glaciated during the Pleistocene epoch. Huge valley glaciers moved down canyons along the western side of the lake, scouring away loose rock and building up great piles of morainal debris. Along the eastern side, glaciers developed only on the shaded side of the highest peaks; so most of this area was not glaciated. This accounts for the subdued topography typical of the Carson Range, as contrasted to the rugged Sierran crest on the west side of the basin.

Climate of the region is strongly influenced by topography. Marine air from the Pacific Ocean, 150 miles to the west, drops its moisture (mostly as snow) as it rises over the crest of the Sierra. Average annual precipitation ranges from more than 50 inches on the western side of the region to about 25 inches along much of the eastern shoreline. The Weather Bureau at Tahoe City, on the west side, reports long-term average snowfall of 213 inches. The fairly long summers are comparatively cool; mean maximum temperature at Tahoe City in July over a 50-year period was 78°F. Winters are cold but seldom severe; mean daily minimum temperature for January over the same period was 17°F. The high elevation and cool temperatures result in a short growing season – an average of only 70 to 120 frost-free days per year at various points near the Lake.

Vegetation includes desert, montane, and alpine species typical of the eastern slopes of the Sierra. Pine and fir forests were heavily logged between 1860 and 1900 when demand for lumber and props for the Nevada silver mines was high. Even so, today the region has good stands of conifers between the Lake level and 9,000 feet, plus considerable areas covered by chaparral and other brush. On fairly level open areas that have a few inches of soil, grasses and other herbage flourish during the short growing season.

Numerous species of wildlife inhabit the Lake Tahoe Region. Deer, bear, mountain lion, coyote, rabbit, raccoon, and several rodents are common. Land birds and waterfowl are present in small numbers consistent with available habitat. Heavy commercial fishing in the Lake around 1900 depleted native populations of cutthroat trout and whitefish, but kokanee salmon and several species of fish stocked from state hatcheries provide good recreational fishing today. Numerous tributary streams also provide sport fishing.

Soils are generally shallow and highly erodible – easily disturbed and slow to stabilize – but the soil is fairly deep in some bottom lands and glacial debris areas. The varied climate and highly erodible soils combine to make the Lake Tahoe region a fragile environment. Hence the ecological balance is easily upset. Whenever vegetation is removed, it is not soon replaced. Erosion by wind and water is a constant hazard; it damages pristine features of the Lake, including the spawning areas of native fish.

Changing Environment

Before the white man invaded this area about the middle of the 1800's, the somewhat nomadic Washo Indian tribe inhabited it. Their name for the lake, "Tahoe," has been variously translated as "big water," "high water," or "water in a high place." The first recorded white visitors were John Fremont's exploring party (1844); they were soon followed by the Forty-niners and other western migrants and adventurers.

During most of the following 100 years, Lake Tahoe was the summer recreation area for wealthy Californians, mostly from San Francisco and the Sacramento Valley. The few summer resorts, scattered stores, service stations, and restaurants hardly marred the natural beauty of the region.

Soon after World War II all this began to change. With increased general affluence, steadily and rapidly increasing numbers of vacationers began to visit the area; their visits gradually extended the "season" from summer to the full year. Establishment of year-round casinos at Stateline in 1955 and the phenomenal growth of winter sports added to the influx of both visitors and residents. By unofficial count in 1965, the region had nearly 29,000 yearlong residents – more than double the 1960 federal census figure. Present projections anticipate more than 50,000 residents by 1980 and an added summer population topping 250,000.

These projected increases in resident and transient populations will inevitably multiply and intensify the environmental problems that already are plaguing the area. Hence the crucial need for planning orderly development that can be sustained by the natural capacities of the region.

Administrative and Governmental Responsibility

The Planning Area established by the Bi-State Planning Compact between the States of California and Nevada is a basin covering 327,878 acres including the 122,628 acres of lake surface. Governmental jurisdiction over land in the Lake Tahoe Planning Area is complex (table 1). The Area is divided between California (Placer, El Dorado, and Alpine counties) and Nevada (Washoe and Douglas counties and Carson City). This division of governmental responsibility makes it difficult to coordinate the administration of government in the Area in the interest of protecting the environment.

Nearly half (48.7 percent) of the land area is federally-owned – chiefly in three National Forests totaling 107,762 acres. An additional 4.5 percent is state owned, nearly all in State Parks. Thus about 53 percent of the land in the Planning Area is publicly owned.

Of nearly 75 miles of lake shoreline, about 18 percent is publicly owned. This is chiefly 8 miles belonging to the State of California and 5.5 miles in National Forests.

Table 1. – Land acreage, by jurisdiction, Lake Tahoe Regional Planning Area, February 1971

Jurisdiction	Gross acreage	Federal land acreage[1]	State park acreage	Private land acreage
Federal:				
Eldorado N. F.	85,518			
Tahoe N. F.	12,060			
Toiyabe N. F.	10,184			
Bur. of Reclamation	64			
	107,826	107,826		
State:				
California	3,552		3,552	
Nevada	6,047		6,047	
	9,599		9,599	
Counties and Cities:				
Alpine	4,170	4,170	0	0
El Dorado	96,887	81,348	3,535	12,004
Placer	46,291	12,124	17	34,150
Washoe	19,700	2,731	3,020	13,949
Douglas	23,538	6,619	709	16,210
Carson City	5,830	834	2,318	2,678
South Lake Tahoe City	5,482	0	0	5,482
Total land area	201,898	107,826	9,599	84,473
Lake Tahoe area[2]	122,628			
Small lakes area	3,352			
Total, Lake Tahoe Region Planning Area	327,878			

[1] *National Forest land except 64 acres in Placer County controlled by the Bureau of Reclamation.*
[2] *At legal elevation of 6,229.1 feet above mean sea level.*

Tahoe Regional Planning Agency (TRPA)

The Tahoe Regional Planning Agency began work as soon as the governors of California and Nevada signed the proclamation creating the Bi-State Planning Agency. Public Law 91-148 had enumerated the dangers of deterioration of the natural environment at Tahoe and of the increasing demands on various natural resources and features of the Region; also, it emphatically stated the need to maintain equilibrium between the Region's natural endowment and limitations on one hand and the environment that man is creating. It recognized need for establishing "an area-wide planning agency with powers to adopt and enforce a regional plan of resource conservation and orderly development, to exercise effective environmental controls, and to perform other essential functions . . . "

TRPA was ordered to develop and adopt, within 18 months of its formation (i.e. by September 1971), a plan for regional development that would include separate plans for land use, transportation, conservation, recreational development, and public services and facilities, to name a few. The Agency was further directed to consider and to seek to harmonize the needs of the whole Region with the plans of local governmental units and the existing land use plans of State and Federal agencies.

Since nearly half of the land area in the Lake Tahoe Region is in National Forests, the Forest Service has major responsibility for improving environmental features here. In 1970 it established the Lake Tahoe Basin Planning Team to work with TRPA. Although the Agency and Team have separate organizations and responsibilities, they have cooperated closely to achieve a common goal.

HYDROLOGY OF THE LAKE TAHOE REGION

"Hydrology is the study of the waters of the earth, their occurrence, distribution, and movement." (Crippen and Pavelka, 1970)

Hydrology is not yet an exact science, but it includes study of atmospheric physics, hydraulics, chemistry, and biology. This paper is concerned with the sources of water in the Lake Tahoe Region, movement of this water within the Lake basin, the forces that act upon it, and its manner of leaving the area. It explains features of the normal hydrologic cycle with reference to special local conditions; it discusses effects of urbanization on the hydrologic cycle and recommends procedures for ameliorating adverse effects. This report is based in part on detailed studies, reconnaissance level data, and data obtained from other geographic areas that seemed to apply to the Lake Tahoe Region. Some other planning guides in this series (e.g., geology, soils, and vegetation of the region), published as part of the planning effort, include information related to the hydrology.

In this study, the quantities involved are tremendous: a single winter storm that brings 2 inches of water within 2 or 3 days as rain or snow carries more than 70 tons of moisture. Its ultimate disposition is determined by the physical and chemical actions to which it is exposed. At best we can only generalize about quantities and forces, for the random variations that occur from time to time and from place to place would largely nullify precise measurements.

Definition and discussion of the basic hydrology of this area are designed to provide guidance for the Tahoe Regional Plan. This information is essential for planning to prevent further degradation of the Lake and the Region.

BASIC DATA

The four types of basic hydrologic data that have been gathered here are measurements of snow depths and water contents, total precipitation (rainfall and water equivalents of snowfall), evaporation of water from a standard 4-ft. diameter pan, and temperature. The records of precipitation, evaporation, and temperature have been taken at only a few points, most of them near the Lake. Outflows from the Lake into the Truckee River have been measured daily since 1901, and accurate records of the level of the water in the Lake have also been kept. These measurements of annual outflow are the most accurate statistics available; the outflows have ranged from 4,700 acre feet to 657,000 acre feet.

Tabulation of quantities of inflow of water to a region and the quantities leaving the region is called a "hydrologic budget." Data for the hydrologic budget of Lake Tahoe (table 2) are informative but must be read with care because they can easily be misinterpreted. Slopes of the Lake Tahoe basin are drained by numerous streams. Average annual water yields by subbasins for these streams (table 3) are based on long-term records of outflow.

Records of winter snowpack show a range from 16 to 220 inches, with an average water content of 7 to 43 inches, depending on depth. Deepest snowpack is usually on the east side of the west rim of the basin (U. S. Department of Agriculture, 1970). Avalanche hazards are present, but discussion of them is outside the scope of this publication. However, planners should be aware of need to have qualified persons study carefully any project proposed for steep slopes.

Table 2. – Estimated statistics of the annual hydrologic budget of the Lake Tahoe Basin, 1901-1966

(From USGS Water Supply Paper 1972)

Component	Mean	Median	Standard deviation	Maximum	Minimum
Runoff to Lake after diversion ...... inches ...	18.5	17.0	8.0	41.5	4.6
Precipitation on Lake inches ...	20.9	20.5	4.2	35.0	12.8
Evaporation from Lake inches ...	34.6	35.2	3.3	39.5	28.2
Net runoff from basin[1] acre-feet ...	172,000	155,000	205,000	767,000	[2]-194,000
Outflow to Truckee River[3] acre-feet ...	171,000	152,000	119,000	657,000	4,700
Range in state .... feet ...	2.27	1.97	0.94	4.9	0.8

[1] *Represents outflow to Truckee River if year-end level were always the same.*
[2] *Negative value reflects excess of evaporation from the Lake over the sum of inflow and precipitation on the Lake.*
[3] *Outflow as it actually occurred.*

Note: 0.3 inch of runoff is diverted from the basin and, therefore, does not reach the Lake. Highest Lake stage: 6,231.26 ft., July 1907. Lowest Lake stage: 6,221.74 ft., December 1934.

Table 3. – Average annual yield of water to Lake Tahoe from surrounding sub-basins[1]

Sub-basin number	Creek or drainage[2]	Area	Precip-itation	Water production	Runoff	
		Acres	*Inches*	*Ac-ft/yr*	*Inches*	*Ac-ft/yr*
1	Tahoe State Park	860	29.0	2,080	16.5	1,180
2	Burton	3,700	28.8	8,910	16.3	5,020
3	Barton	660	24.0	1,320	12.2	670
4	Lake Forest	400	22.5	750	9.5	320
5	Dollar	1,100	21.6	2,000	8.5	790
6	Cedar Flats	1,260	22	2,310	9.2	970
7	Watson	1,540	25	3,210	12.2	1,570
8	Carnelian Bay	550	23	1,050	10.1	460
9	Carnelian	2,980	24.6	6,110	11.6	2,890
10	Tahoe Vista	2,670	24.7	5,500	11.7	2,600
11	Griff	3,190	25.8	6,860	13.0	3,460
12	Kings Beach	870	22.6	1,640	9.6	700
13	East Stateline	840	22.9	1,610	10.0	700
14	First Creek	900	24.8	1,860	12.0	900
15	Second Creek	1,220	24.9	2,530	12.1	1,230
16	Burnt Cedar	530	24.0	1,060	11.2	500
17	Wood	1,400	24.7	2,880	12.0	1,470
18	Third Creek	3,720	25.6	7,930	12.6	3,800
19	Incline	4,270	23.9	8,500	11.0	3,910
20	Mill	1,200	22.5	2,250	9.5	950
21	Tunnel	1,010	22.0	1,850	9.2	780
22	Unnamed	670	20.0	1,120	7.0	390
23	Sand Harbor	1,050	21.0	1,840	8.1	710
24	Marlette	3,100	20.4	5,260	7.3	2,000
25	Secret Harbor	2,710	19.4	4,380	6.2	1,400
26	Bliss	590	19.9	980	6.8	330
27	Deadman Point	670	17.5	980	4.5	250
28	Slaughter House	3,180	19.5	5,160	6.3	1,670
29	Glenbrook	3,480	19.2	5,560	5.9	1,710
30	North Logan House	1,100	19.8	1,810	6.7	610
31	Logan House	1,450	19.8	2,400	6.7	810
32	Cave Rock	1,040	20.0	1,740	7.0	610
33	Lincoln	1,610	19.8	2,660	6.7	900
34	Skyland	480	19.5	780	6.3	250
35	North Zephyr	1,530	19.9	2,540	6.8	870
36	Zephyr	870	19.9	1,450	6.8	490
37	South Zephyr	320	19.9	530	6.8	180
38	McFaul	2,650	19.9	4,400	6.8	1,500
39	Burke	3,290	24.6	6,750	11.6	3,180
40	Edgewood	3,780	29.7	9,350	17.3	5,450

Sub-basin number	Creek or drainage[2]	Area	Precip-itation	Water production	Runoff	
		Acres	*Inches*	*Ac-ft/yr*	*Inches*	*Ac-ft/yr*
41	Bijou Park	2,680	28.8	6,430	16.3	3,640
42	Bijou	1,870	25.8	4,020	13.0	2,030
43	Trout	25,400	32.4	68,600	20.2	42,800
44	Upper Truckee River	36,330	32.1	97,900	19.9	60,200
45	Camp Richardson	2,140	23.0	4,100	10.1	1,800
46	Taylor Creek	12,270	41.0	41,900	29.7	30,300
47	Tallac	2,830	30.4	7,160	18.1	4,270
48	Cascade	3,100	37.4	9,660	25.6	6,600
49	Eagle Creek	5,940	39.3	19,500	27.7	13,700
50	Bliss State Park	680	22.0	1,250	9.2	520
51	Rubicon	2,010	29.3	4,920	16.8	2,810
52	Paradise Flat	900	29.5	2,970	17.1	1,280
53	Lonely Gulch	790	31.4	2,060	19.1	1,260
54	Sierra	760	30.2	1,920	17.8	1,130
55	Meek's	5,930	37.1	18,300	25.2	12,400
56	General	5,790	39.4	19,000	27.8	13,400
57	McKinney	3,260	34.8	9,450	22.7	6,160
58	Quail	1,100	33.0	3,060	20.9	1,930
59	Homewood	580	33.0	1,600	20.9	1,050
60	Madden	1,720	33.6	4,810	21.6	3,100
61	Eagle Rock	560	32.0	1,490	19.9	940
62	Blackwood	7,660	42.0	26,700	30.7	19,600
63	Ward	8,240	39.0	26,800	27.5	18,900
Totals		201,000		515,000		307,900
Average			30.8		18.4	

[1] *Data from Lake Tahoe Area Council.*
[2] *Some of these names of streams still must be verified.*

Sedimentation in streams in the California portion of the Lake Tahoe region was carefully studied and reported in 1969 by the Resources Agency of the State of California. Use of fertilizers on lawns, golf courses, and disturbed areas to promote growth of grass and other plant cover for soil stabilization is known to be a source of nutrients to streams and to the Lake, but no precise data are available.

Water rights

A related problem is water rights. Through the years there has been extensive litigation over these rights. In 1955, legislative action established the California-Nevada Interstate Compact Commission to negotiate and enter into a compact providing for equitable distribution and use of the waters of the Truckee, Carson, and Walker rivers and Lake Tahoe in both states. This Compact has allocated 34,000 acre-feet of water annually for use in the Lake Tahoe Region – 23,000 acre-feet to California and the remaining 11,000 to Nevada. This Compact was ratified by both States and was introduced in the first session of the 92nd Congress on March 15, 1971, for ratification by the federal government.

Water rights of the two states in acre-feet can be summarized briefly thus:

	Estimated use (1969)	Recorded water right filings*	Compact allocation
California	9,360	60,266	23,000
Nevada	4,576	31,224	11,000

*Includes estimated use in 1969

Laws about water rights in the two states are different, but comparison of the figures in the tabulation above clearly indicates a future problem of water supply.

FLOODS

Records of destructive floods in the Lake Tahoe Region date back as far as 1861, but these events were scattered and the dollar value of their damage was small because the area was sparsely populated. Establishment of casinos in Stateline in 1955 and spectacular increase of winter sports dating from establishment of the Heavenly Valley Ski Area (1959) and the Winter Olympics at Squaw Valley (1960) changed all this. These three events led to sharply increased population of the area; this, in turn, led to increased hazard from flooding and to increased dollar costs of subsequent damage. Here we are concerned strictly with the kinds and seriousness of flood damage to the ecosystem. The formerly open areas around the Lake became heavily urbanized; this meant that most of the stream outflow areas and floodplains in the California sector of the Tahoe region began to be covered by residences, commercial buildings, streets and highways, and shopping areas.

This accelerated and often ill-planned or unplanned building activity had four main effects that augmented the flood flows and increased damage from them.

1. Homes, individual business buildings, and shopping areas were located so that they encroached upon the floodplains, deltas, and highwater limits of streams (notably Trout Creek and the Upper Truckee River).
2. Removal of extensive acreages of tree, grass, and brush cover accelerated runoff and buildup of flood conditions. This good watershed cover was succeeded by bare or sparsely covered slopes (e.g., Heavenly Valley Ski Area) and large areas of pavement (for streets, highways, and parking areas) and rooftops.
3. The great increase of rooftop and pavement area has greatly increased the potential for rapid runoff, overland flow, and buildup of flood water.
4. Widening of U. S. Highway 50 from Stateline to Meyers from two lanes to four lanes, plus raising the grade as much as 3 feet in some low areas, aggravated the ponding of flood waters in many low spots. The widened and raised roadway acts as a sluiceway at some points, as a dam in others, especially where the new construction did not provide adequately increased drainage.

Damage from storms

Three types of weather phenomena have caused flood, erosion, and sediment damage in this drainage: wet-mantle floods, dry-mantle floods, and rain on snow or on frozen ground. The first and last of these types occur in late winter or early spring and usually cover wide areas, but the dry-mantle flood is a local event resulting from violent summer convection thunderstorms and often causes severe damage. Of the three flood types, the wet-mantle and the rain-on-snow have caused the most destruction on this watershed and on its manmade structures. However, within the past decade two major destructive dry-mantle floods have occurred in this area.

On July 17, 1962, a convection storm centered over the Bijou-Tahoe Valley-Meyers area and dropped from 0.6 inch to nearly an inch of water over this drainage in a very short time. This sudden downpour resulted in considerable overland flow, which quickly raised the Upper Truckee River in Tahoe Valley so that it flooded homes and stretches of U. S. Highway 50 from Stateline to Al Tahoe. The steep lower slopes of Heavenly Valley Ski Area, bare and easily erodible, were one of the worst flood-source areas in this storm.

Three years later, on August 16, 1965, a heavy downpour hit the whole eastern sector of the Lake area; it was part of a 9-day storm that brought the greatest recorded rainfall since 1901. At Meyers Ranger Station, 4.11 inches of moisture was recorded during this storm; Glenbrook and Tahoe City had about half that amount, and Incline Village had a disastrous flood.

EFFECTS OF URBANIZATION ON FORESTED WATERSHEDS

Stream Channel Behavior

Drainage channels comprise only a small part of any drainage basin, but they are critically important: they provide a well integrated system for exporting sediment and water from the drainage basin; and, through bank erosion and channel extension, drainage channels may produce large quantities of sediment. Since most channels are formed in alluvium, any change in the hydrologic regimen of the drainage area can cause an immediate response in the channel system. Alluvium that has been stored in a valley for thousands of years may, during some major flood event, be flushed out of the system. This is not the sole problem, of course, for this sediment ususally is deposited somewhere downstream.

Of fundamental importance is the concept of a drainage basin as an *open system*[1] tending to achieve a steady state of operation. Because matter and energy enter and leave the system, we can consider an individual stream, as well as a whole drainage basin, to be an open system. Precipitation enters the system, and sediment and excess precipitation are exported from the drainage mouth. Such open systems are characterized by the exchange of material and energy with and continuous interaction on the surroundings, in this case channel, ground surface, and even the air above. In open systems the rate of import and export of material and energy become balanced so that an equilibrium is reached; this equilibrium is called the *steady state.*

If we study a stream over a long period of time, we find that the fluctuations in its load and flow are minimal and that the discharge and load can be considered constant. When the rates of import and export of material are in balance, i.e., when the channel is *stable* and is neither eroded nor silted up, the stream has reached the steady state. The steady state is achieved and maintained by mutual interaction of such channel characterisitcs as gradient, cross-sectional form, roughness, and channel pattern. It is a self-regulatory system; hence, any change in the controlling factors will cause a displacement in a direction that will tend to absorb the effects of the change.

The purpose of this discussion is to consider possible upsets and readjustments of the steady state in a stream system as a result of urbanization.

A Changing Environment

Conversion of forest to residential areas, roads, parking lots, lawns, and other urban uses significantly affects the hydrologic environment. Runoff from undisturbed forest drainages is kept to a minimum by high capacities for infiltration and absence of overland flow. The effects of forest cover on hydrologic processes derive from the fact that trees transpire through their leaves; this transpiration, in turn, depletes soil moisture and creates storage potential. This increased storage potential prevents most precipitation from reaching the stream channel. A forest also intercepts moisture either in the crowns of trees or in the ground litter. In winter, conifers, intercept and evaporate from 18 to 25 percent of the precipitation, depending upon how much of it falls as snow (Lull and Sopper, 1969). Consequently, removal of forest directly influences runoff by increasing snow accumulation and melt. Because of snow drifting and reduction of interception, maximum accumulation of snow is greater in the cut than in the uncut forest. Anderson (1956) reported snow accumulation being 12 inches greater as a long-term average in the central Sierra Nevada. Clearcuts that create large open areas not only store more snow than does a forest, but they have much more rapid melt. Anderson estimated a long-term average of 16 inches of snow water left in the uncut forest at 7,600 feet elevation on June 9 when all snow had melted in large open areas at the same elevation.

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[1] *A system is a set of objects together with relationships between the objects and between their attributes.*

Urban growth is accompanied by considerable increase in impervious surfaces. When large areas of ground surface are covered, their opportunity and ability to absorb precipitation are decreased. The degree of influence depends on the degree of urbanization, expressed most simply as the proportion of the total area covered by an impervious surface. This can range from almost 100 percent in commercial districts to a small percentage in suburban areas. Antoine (1964) gave these percentages of impervious areas for typical urban land uses:

	Percent
Cemeteries	5
Parks and recreation areas	15
Residential lot areas:	
15,000 square feet	25
6,000 to 14,000 square feet	40
5,900 square feet	80
Semipublic and public	75
Industrial	90
Commercial	100

Increased Runoff

Both the increase in impervious area and the decrease in interception, soil-moisture storage, and evapotranspiration combine to increase overland flow and runoff. Storm sewers, built to collect this increased runoff, carry it to the streams much more rapidly than it would flow through natural channels. The combination of more surface runoff and its more rapid transport to the streams greatly increases flood peaks. Several studies of peak flow have shown that they may be increased by 1.2 to 5 times over peaks from rural conditions (Lull and Sopper, 1969). Thus, the frequency at which flows will equal or exceed channel capacity is increased; i.e., there will be more overbank flows or floods per year. Leopold (1968) synthesized data from several studies to show the increase in the average annual flood for degrees of urbanization, defined by increases in percentage of area sewered and made impervious:

Percentage Area Sewered	Percentage of Area Impervious	Ratio to Average Annual Flood
0	0	1.0
20	20	1.5
40	40	2.3
50	50	2.7
80	60	4.2
100	60	4.4

Floods not only damage land and buildings bordering the stream, but they also widen and deepen the channel and utterly disrupt the stream environment. Buildings in the floodplain are dangerous for their inhabitants; they also impede the flow of flood water by constricting the channel and thus increasing velocities downstream. If the flow increases three times, Leopold (1968) estimates that the stream channel for a small drainage area (one-quarter square mile) will be scoured to twice its prior width and half again its prior depth.

The precise effect of urbanization on sustained low flow during summer or non-rain periods is difficult to establish. In principle, it is clear that if, during an average year, a larger percentage of the precipitation reaches the stream as surface runoff as a result of an increase in impervious areas, then a smaller percentage of the precipitation will have been stored in the ground. It is expected, there-

fore, that in addition to urbanization increasing the size and frequency of floods of moderate size, it will tend also to reduce stream flow having its origin in ground water flowing to the stream during non-storm periods (figure 1).

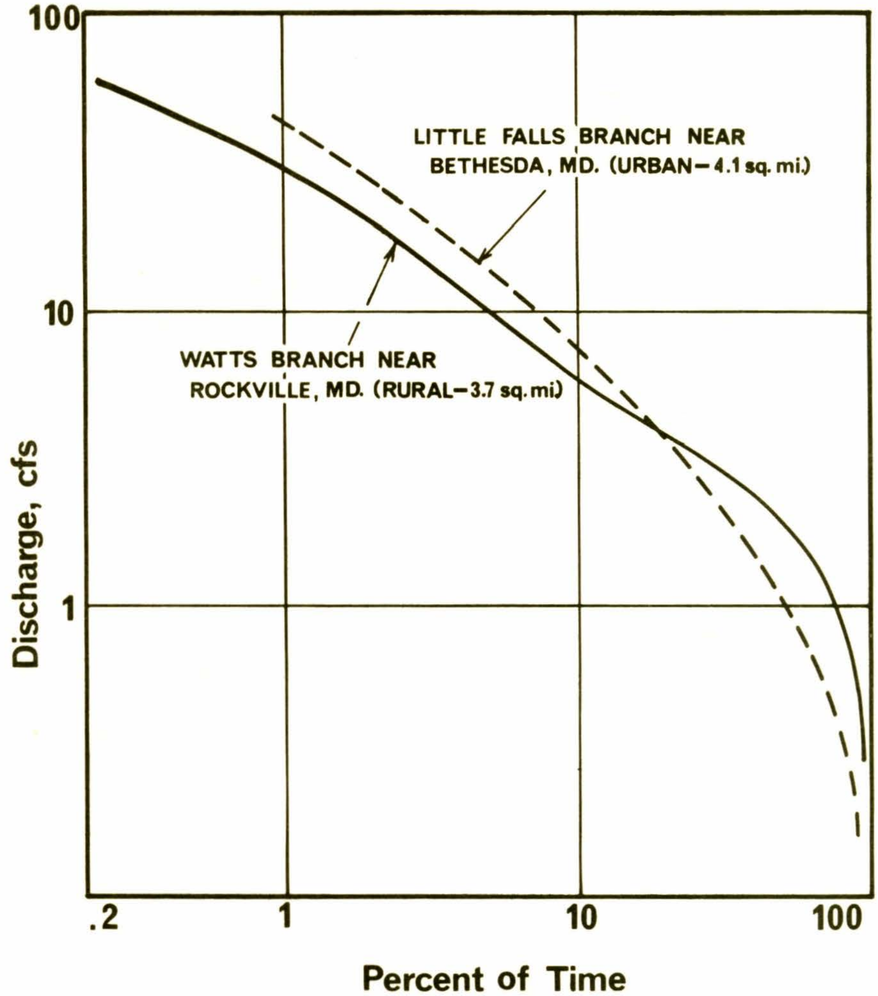

Figure 1. – Flow duration curves for an urban and rural watershed (adapted from Leopold, 1968).

Figure 1 shows duration of flows in two small watersheds (less than 5 square miles) near Washington, D. C. – one rural, the other urbanized. During 2 percent of the time the urbanized watershed has a flow exceeding 27 cubic feet per second, whereas the rural one has a flow exceeding 20 cubic feet per second. The low flow end of the curve shows that 50 percent of the time the flow from the urbanized watershed is 1.2 cubic feet per second or less, while the rural watershed has a better sustained flow of 2 cubic feet per second. During 50 percent of the time the larger drainage area provides less water than the smaller one.

During summer or non-rain periods, sustained flow provides more water to dilute materials occurring naturally in the water or introduced into it. The failure of an urbanized drainage basin to sustain its flow would result in greater concentration of pollutants at those times.

Protective measures

Removal of forest cover and laying down impervious surfaces in its place necessarily accompany urbanization, but their effects on runoff can be considerably reduced. As a general principle, development projects should be located as far from streams as possible so that some of the runoff from impervious surfaces can be absorbed by the ground enroute to the stream. Natural cover should be maintained near streams to aid in the infiltration of precipitation and surface runoff. Peaking effects can be reduced by providing storage areas for the increased runoff from which it can be released gradually. These storage areas can take many forms, including small dams, and catchments in parking lots of large buildings or along the roadside.

Finally, flood damage can be kept to a minimum by preventing land development in the flood plain.

Increased Sedimentation

During development and construction in suburban areas, sedimentation usually is greatly increased. Depending on soil, slope, previous use, and construction methods, sedimentation during construction in suburban areas may be 500 to 1,000 times as much as that from protected forested watersheds. Even after construction is completed, sedimentation may be 5 to 10 times as high. The marked increases in sedimentation resulting from changed use of natural forest land in the vicinity of Washington, D. C., have been reported (O'Bryan and McAvoy, 1966) as follows:

Land condition	Sediment yield (Tons per sq. mile per year)
Forest land	about 50
Urban and suburban land	50 to 100
Farmland	1,000 to 5,000
Stripped for construction	25,000 to 50,000

Streams in their undisturbed state tend to be in adjustment with the sediment load they have been receiving through the centuries. The variety of types of sediment moved through the channel system causes a significant difference in the alluvial material of the the flood plain, and as a result, channel adjustments take different forms. We here consider only the end members of the continuum of the channel types. The banks of suspended-load channels are relatively cohesive and resist erosion; therefore streambed erosion predominates during instability, whereas bank erosion predominates in bedload channels.

Let us now consider the lower reaches of many streams in the mountainous West – the bedload channel. These streams occupy relatively narrow, steep-sided valleys filled with coarse alluvial de-

posits. These deposits form a plain characterized by a level surface between the valley walls, scarred with evidence of abandoned channels, old gravel bars, and flood debris, and over which a sinuous stream of low gradient flows.

Numerous studies have shown how human interference with drainages has grossly upset the magnitude of certain controlling factors within the system, as evidenced by the effect that hydraulic mining had on certain Sierra Nevada streams during the later nineteenth century. A change in the type and/or quantity of sediment due to changes in land use may silt up a channel by the deposition of a sediment load that is too great to be carried by the available discharge.

The filling of stream channels reduces channel capacity and thereby increases the severity of flooding. When flood waters subside, they drop quantities of sediment and vegetal debris, partially choking the channel. These obstructions divert flow and increase erosional attack upon the banks and add more sediment to the channel system. Diversion may result in lateral migration of the channel by erosion of one bank and deposition along the other bank. Gradually the channel becomes wider and shallower and the velocity of water flow across the bottom is reduced.

This slowing of flow reduces the scouring on the stream bottom and leads to future buildup of sediment and the choking of the channel with plant life. Subsequent floods, due to lack of channel capacity, are diverted on the flood plain and actively erode a new channel.

Sediment from these upstream disturbances is transported downstream where the coarse material is available for selective deposition. Thus a downstream cycle of erosion and sedimentation has been activated by attempts of the channel to adjust to a flow and sediment load too large to be carried with its present morphologic characteristics. These adjustments take many decades, or longer, to accomplish and result in a shifting pattern of channel location along the valley bottom from one flood to the next. During this period, the aquatic habitat becomes severely deteriorated and unstable, and the amount of sediment available for downstream sedimentation is greatly increased.

The natural equilibrium between the stream's ability to handle sediment and the load which it receives should be maintained insofar as possible. Several approaches can be combined to minimize erosion and transport of sediment to stream channels. The most obvious is to restrict development and tree cutting on steep slopes where sediment yield is very sensitive to disturbance. The amount of cut and fill in an area can be limited; other tree cutting can be restricted; mulching or seeding of exposed surfaces can be required; and a maximum limit can be set for the proportion of a given area which can be exposed at any one time. Developers can be required to build catchment basins to trap any sediment that runs off despite these preventive measures.

Even when the measures listed above are used, some sediment will be carried away from development sites. To impede it from reaching streams, buffers of land adjacent to them can be kept in forest or meadow to catch the sediment as spring melting and storms carry it overland.

Degraded Water Quality

Urbanization has two principal effects on water quality. The first is the influx of waste materials, which increases the content of dissolved solids (including nutrients) per volume of water, decreases the dissolved oxygen content, and may introduce toxic or pathogenic materials. The second effect is that, as the increased area of imperviousness and decreased lag time promote the increase of flood peaks at any given frequency, less water is available for percolation to recharge ground water and to provide base flow to dilute the pollutants.

Under natural conditions, less than 10 percent of the streamflow originates as direct surface runoff. When large areas of forest are removed and covered by an impervious surface, the proportion of

streamflow originating as surface runoff increases sharply. As a direct consequence, streams most affected by street runoff may develop temperature patterns that are markedly different from those observed in streams flowing through natural channels. By greatly increasing the surface area exposed to solar radiation, the removal of vegetal canopy can greatly increase the stream's temperature and alter its biotic community. Removal of the riparian vegetation also can be expected to profoundly affect stream temperature regimen. Studies have shown that stream temperatures in urban areas in summer may be 10° to 15° F above the temperature in unurbanized control streams. Temperatures in reaches most affected by ponding, realignment, or clearcutting of streamside vegetation are most significantly higher in summer; but winter temperatures are 5° to 10° colder than those measured in reaches unaffected by man's activities. Diurnal temperature fluctuations are substantially less in natural streams.

Treatment of waste is essential; however, stream quality also can be protected by preserving buffers of undeveloped land adjacent to streams. The buffers filter out some pollutants and provide shade for the stream water.

Summary

Study of the usual effects of urbanization on the hydrologic system shows that these effects take the following forms: increased flooding, decreased water supply, increased erosion and sedimentation, and decreased water quality. These effects are caused by some unavoidable concomitants of urbanization: decrease in natural vegetative cover, increase in impervious surfaces, extensive storm sewerage, and increased use of water and discharge of wastes. Since urbanization, and these accompanying changes in use of land and water are to be accepted, the problem is to manage urbanization so that the usual deleterious effects on water resources are avoided or kept minimal.

Having determined what areas are most critical for protection of water resources the problem remains of defining these areas precisely. Present hydrologic knowledge is insufficiently precise to let us construct a family of curves relating hydrologic deterioration to characteristics of land or land use – for instance, sedimentation and distance of disturbance from the stream. The few curves which it has been possible to construct show no break points in the rate of deterioration. On the basis of present knowledge, it can be said that the steeper the slope that is developed, and the nearer that development is to the stream, the greater the impervious coverage, or the less vegetation, the greater will be the damage to water resources.

PREDICTION OF RUNOFF AND SEDIMENT PRODUCTION

Several methods have been devised for predicting runoff and yield of sediment. They are analytical techniques that attempt to describe a very complex natural process. Limiting assumptions are made mainly because of present lack of specific knowledge about many of the natural parameters. The basic procedure is to use a system to predict and then to gather field data; these data may either confirm or modify the prediction system.

A local study made on the Blackwood, Glenbrook, and Upper Truckee River drainages has evolved a tentative system. These three drainages were selected for study because they provided a good range of the Tahoe Region's climatic conditions and soils and because good water flow records were available. Results of this study to date appear promising, but the authors[2] are still refining their procedures.

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[2] *Suhr, W., and J. Kress. "On-site runoff and sediment prediction for soil-landform units of Tahoe Basin." (On file with U. S. Forest Service Tahoe Basin Planning Team.)*

PROBLEMS, CONSEQUENCES, AND SUGGESTED SOLUTIONS

This section points out five problems related to the hydrology of the region and suggests ways by which the objectives of the Bi-State Compact may be met in solving them. Following the statement of each problem is a list of the consequences of not trying to solve it; this is followed by suggested solutions to the problem or approaches to solutions.

I

Problem: Certain naturally hazardous areas have not been recognized.

Consequences:
1. Life and property may be endangered.
2. Increased runoff, erosion, and deposition of silt may have adverse long-term effects on water quality.

Suggestions:
1. Locate, identify, and describe hazardous areas within the Lake Tahoe Region.
2. Restrict zoning in accord with the report of the above survey of hazards (i.e., use the "Standard Project Flood" approach to determine the "Floodway" that the Corps of Engineers uses).

II

Problem: Changes in use of land sometimes produce undesirable environmental effects, such as increasing runoff, amplifying flood peaks, and attenuating base flows.

Consequences:
1. Aggradation and degradation of downstream channels.
2. Possible danger to life and property.
3. Disruption of stream environment.
4. Changes criteria for design of channel-related structures.

Suggestions: Require the proponent of any change in land use to prepare and submit a conservation plan that includes a hydrologic study that shows the on-site and off-site effects of this proposal. The plan should be submitted to and considered by appropriate government agencies. The hydrologic study should be made by qualified experts and should show: 1. how the increased runoff from the proposed project will be stored on site for later release into the stream channels, and 2. how the cumulative effect of the proposed project will change the downstream hydrology.

Establish a streamside environmental zone, which may be an officially established (by U. S. Corps of Engineers "Standard Project Flood" procedures) floodway plus the lesser of 100′ horizontally or 25′ vertically; or it may be a historic floodway as established from geologic evidence, plus the lesser of 100′ horizontally or 25′ vertically. If the second of these types is used, the developer could warrant the adequacy of the determination of the historic floodway. Of the procedures outlined above, the one that determines the wider floodway can be used. These procedures are appropriate for virtually level floodplain land.

On steeper terrain a different sort of procedure is appropriate. Before development can be started along any streamcourse in strongly sloping terrain, an on-site determination of the environmental zone should be made. This determination will be based on the dependent factor of maintaining existing water quality and the inde-

pendent factors of geology, types and density of vegetation, soil type, and side slopes; it should be made by the governmental agencies having jurisdiction and paid for by the developer.

III

Problem: Manipulation of streamflow
1. By augmenting flow at low-flow stage.
2. By augmenting flow at high-flow stage.
3. By interception (e.g., by diversion for irrigation).
4. By drainage of local water tables.

Consequences:
1. Augmentation at low-flow stage would change the stream regime. If low flow enhances the fisheries, it is desirable to maintain it. Flow substantially in excess of a natural minimum could cause undesirable channel erosion.
2. This augmentation at high flow would cause aggradation and degradation of downstream channels.
3. Interception can cause downstream channel degradation and may adversely affect aquatic habitat and riparian vegetation.
4. Drainage would lower local groundwater tables; this would destroy marshes and riparian vegetation and thus drive out waterfowl, shore birds, and other wildlife.

Suggestion: An environmental determination could be made in accordance with the National Environmental Policy Act of 1969 (P.L. 91-190). Each proposal for manipulation can be evaluated for its possible consequences, both desirable and adverse. Evaluation should also carefully consider all hazards of operational or structural failure.

IV

Problem: Possible improper management of the surface level of Lake Tahoe.

Consequences:
1. Storms that occur when the water level is high can cause erosion of the shoreline, which, in turn, degrades the quality of the water.
2. A certain water level may cause streams to form sandbars and prevent fish from migrating upstream to spawn.

Suggestion: Study present method of control of the surface level of the Lake and determine whether some other level would be more desirable.

V

Problem: Manmade climatic changes, such as weather modification ("rainmaking"), intended to increase streamflow.

Consequences:
1. Erosion of channels could be accelerated
2. Larger culverts and bridges would be needed.
3. The balance of vegetation could shift from types that use little water to types that use a great deal.

Suggestion: Refer the problem to the Climate and Air Pollution Committee. Restrict "rain making" operations to seasons that have subnormal precipitation.

RESEARCH NEEDS

Adequate hydrological data for the Lake Tahoe Region are not available. Such data are urgently needed to provide bases for sound decisions on land use. A paper by G. F. Worts, Jr., and P. A. Glancy of the United States Geological Survey titled "A Proposal for Cooperative Hydrologic Investigations in Lake Tahoe Basin, Nevada, and California" (1969) proposed the following objectives for a hydrologic investigation of the Lake Tahoe Region:

"1. Develop hydrologic knowledge in areas that are presently unaffected by man's development in order to form a basis for understanding the natural hydrologic regimen of the Basin, to provide the necessary reference when assessing or predicting the effects of future human activity, and to attempt to correlate hydrologic conditions in undeveloped or lightly developed areas with those in developing or developed areas.

"2. Establish a surveillance data-collection network where urbanization is taking place or is imminent, the purpose of data collection being the establishment of a chronologic documentation of the effects of man's work on nature.

"3. Develop broad and specific areas of understanding of natural hydrologic conditions in the Basin which would allow planners to anticipate or predict the effects of natural hydrologic events on the lives of man.

"4. Develop knowledge on natural and man-modified hydrologic conditions peculiar to the Tahoe Basin that should allow management to minimize man's destructive effects on his fellow man and thereby reduce the need for affected people to seek legal restitution from each other or governmental groups because of error in hydrologic judgment or management.

"5. Assess the contribution to Lake Tahoe water via surface and underground flow.

"6. Provide information on the ground water flow system from Tahoe Basin aquifers to the lake which would allow assessment of the long-term effects of existing septic systems on the quality of lake water."

Methods of Study

Although immediate results of a full-scale detailed hydrologic investigation would be desirable for use in planning and management, a detailed study probably is not now feasible, nor would immediate results be available regardless of feasibility. Therefore, a moderately intensive hydrologic study of the Lake Tahoe Basin is recommended for initiation in the 1970 fiscal year (July 1969-June 1970). This study should be designed to provide information necessary to begin formulating solutions to the region's hydrologic problems and to attain the objectives previously stated. Results of the study will allow a sharpening of focus on specific present and future problems, and will arrange the problems according to priority for implementing effective solutions or alternatives. Therefore, this proposed study, in addition to the establishment of a hydrologic-data measurement network, would also form a basis for evaluating all or part of the following specific hydrologic parameters:

1. Annual surface runoff and flow duration of streams tributary to Lake Tahoe.
2. Quantitative data on movement of fluvial sediment.
3. Specific characteristics of runoff with regard to type and magnitude of storms, including frequency and magnitude of floods in the general area, and on specific streams.
4. Effects of natural drainage basin characteristics on runoff and fluvial erosion.
5. Effects of man's development on erosion conditions.
6. Effects of runoff and erosion on the works of man.
7. Effects of erosion and movement of sediment to the Lake with regard to the supply of chemical nutrients that accelerate eutrophication.

8. Characteristics of erosion in the Tahoe Region and their likelihood of occurrence under given conditions (sheet and rill erosion, fluvial channel erosion, landslides, creep, etc.).

9. Delineation of ground water reservoirs and estimates of ground water in storage.

10. Ground water flow systems with respect to discharge into Lake Tahoe (to determine long-term effects of discharge of existing septic tank installations).

SUMMARY AND CONCLUSIONS

Most of the land development activity in the Lake Tahoe Region reveals either lack of awareness of important aspects of the hydrology of the area or else deliberate ignoring of them. Only recently has zoning of floodplain areas been recognized as a need. Local governmental agencies have not yet developed realistic systems for disposal of storm drainage: present practice is simply either to deliver overland flow from storms directly to Lake Tahoe or else to the nearest stream – and without any treatment to reduce its potential for water pollution. No one in authority has recognized that the effect of increased runoff from urban areas into the natural drainage systems is bad. However, some attention is being devoted to on-site problems in developed areas. Some road cuts, ditch lines, and drainage channels are being mechanically stabilized – first steps, but important – toward solving some of the problems caused by land disturbance. But much more needs to be done, for it is inevitable that development will continue in the Tahoe region.

Following careful study of the local hydrology, this committee has come to the following conclusions and hopes that persons who make decisions about land use will be guided by them.

1. The damage to man's installed facilities caused by such natural events as storms and floods, avalanches, and landslides can be held to a minimum by delineating the areas where they have occurred and zoning to avoid them.

2. The adverse effects of increased runoff caused by changes in land use can be reduced by recognizing these effects in advance and modifying the land use accordingly.

3. The consequences of structural manipulation of water can be evaluated by analyzing the short-term, long-term, off-site, and on-site effects of the proposed change.

4. The shoreline erosion of Lake Tahoe could be evaluated in terms of damage done during high water levels and the feasibility of lowering the Lake during periods when storms are most likely to occur.

5. Climatic conditions such as smog or manmade weather modification could be evaluated in terms of their consequences to the natural drainage systems.

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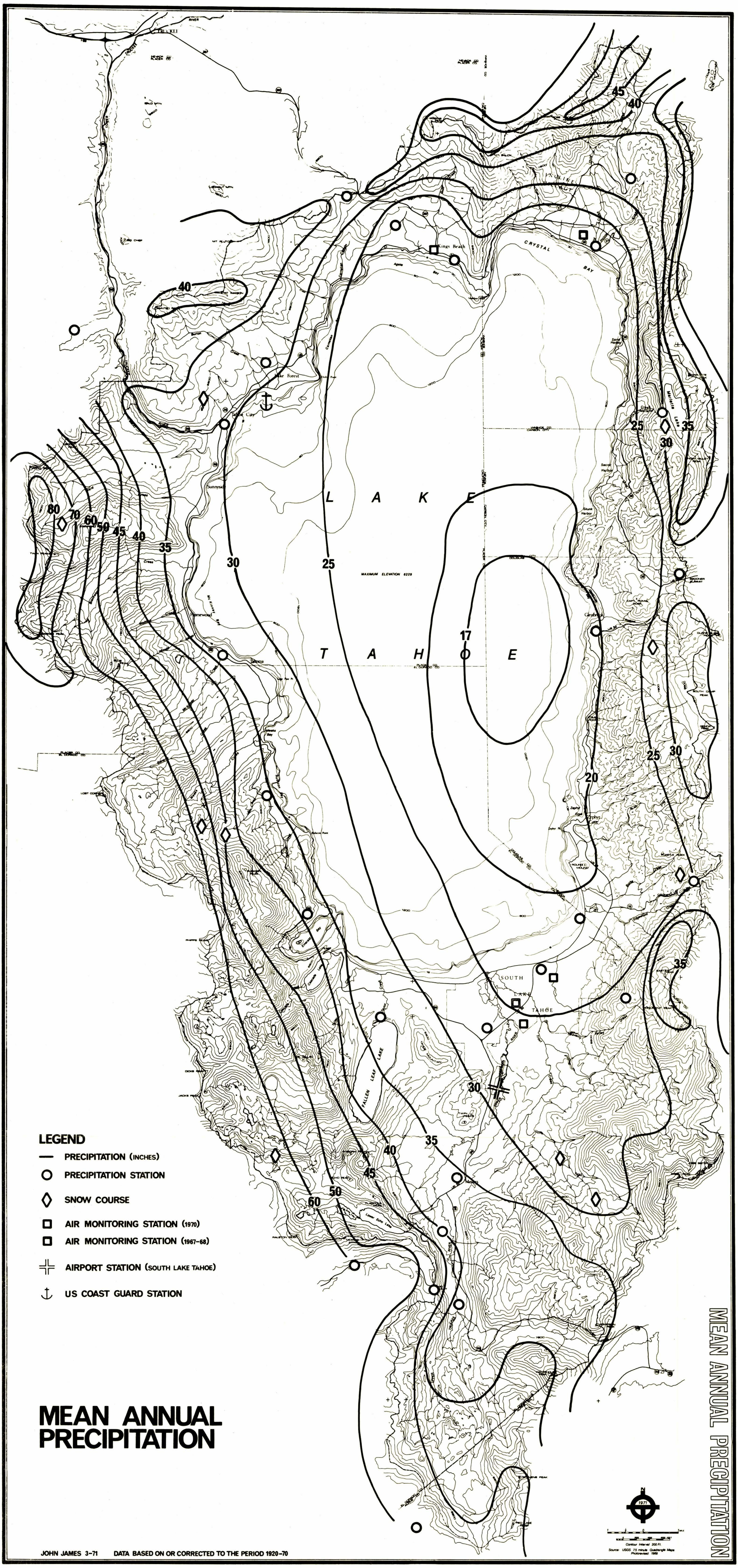

LAKE TAHOE REGION

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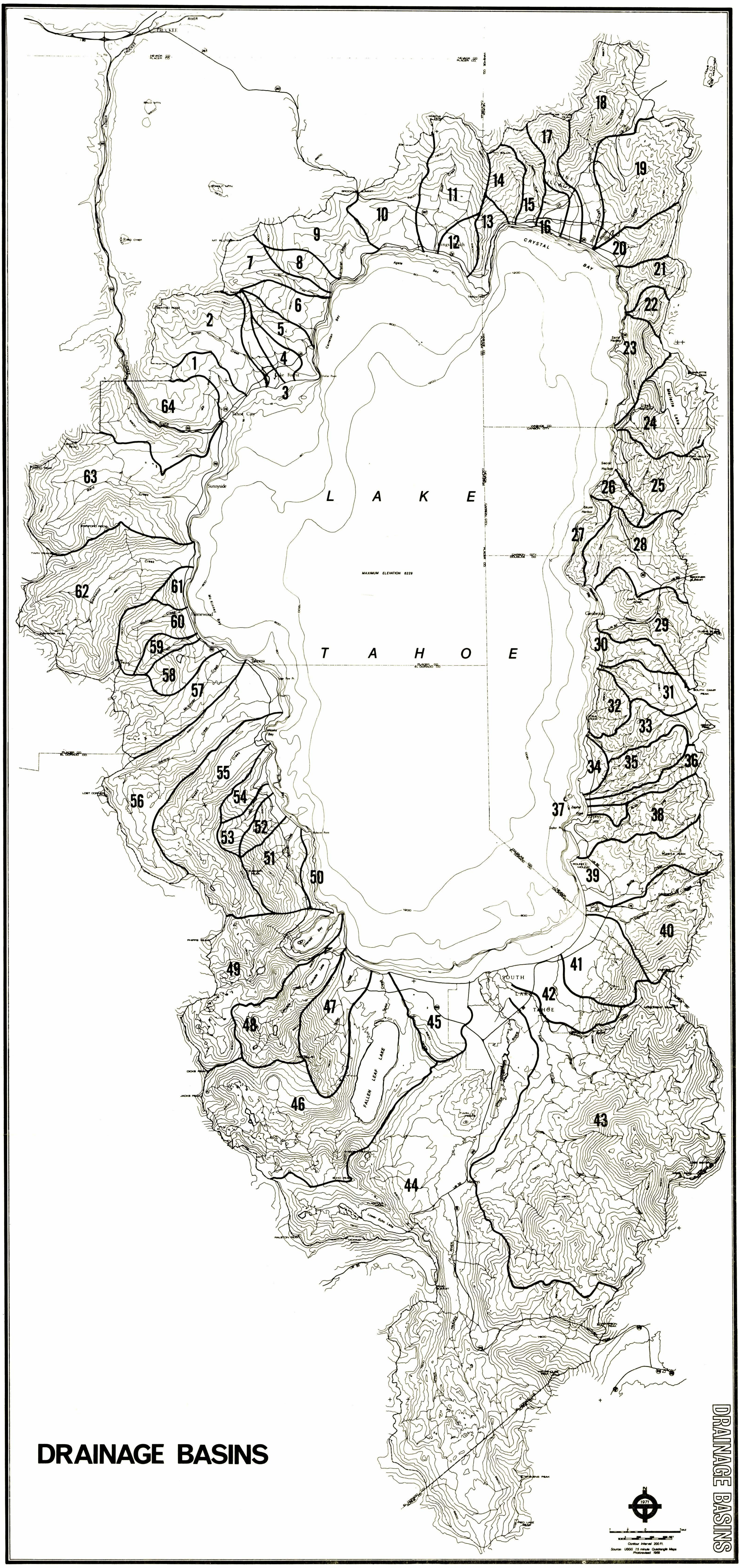

LAKE TAHOE REGION

TAHOE REGIONAL PLANNING AGENCY

USDA FOREST SERVICE

This publication is one of a group issued jointly by the Tahoe Regional Planning Agency and the USDA Forest Service. Each publication describes and inventories a natural resource or other characteristic that is significant to the total environment of the Lake Tahoe Region; it attempts to show the hazards incidental to improperly planned development of the area and to provide information helpful in designing controls that must be implemented if the scenic beauty of the Lake Tahoe Region is to be preserved and its other natural resources are to be conserved. These publications are not exhaustive treatises of their subjects, but they highlight the known significant information and data useful in the planning effort underway. Subjects of publications in this series are:

Climate and Air Quality of the Lake Tahoe Region

Cultural and Historical Significance of the Lake Tahoe Region

Land Resources of the Lake Tahoe Region

Fisheries of Lake Tahoe and Its Tributary Waters

Geology and Geomorphology of the Lake Tahoe Region

Hydrology and Water Resources of the Lake Tahoe Region

Limnology and Water Quality of Lake Tahoe and Tributary Waters

Recreational Resources of the Lake Tahoe Region

Wildlife of the Lake Tahoe Region

Soils of the Lake Tahoe Region

Vegetation of the Lake Tahoe Region

Scenic Analyses of the Lake Tahoe Region

Because of the heavy expense of publication and because these reports are designed chiefly for use by planners, supplies are not available for general public distribution.